

Spectroscopic Identification of a Novel Catalytic Reaction of Rubidium with Atomic Hydrogen and the Hydride Ion Product

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ABSTRACT

From a solution of a Schrödinger-type wave equation with a nonradiative boundary condition based on Maxwell's equations, Mills predicts that atomic hydrogen may undergo a catalytic reaction with certain atomized elements and ions which singly or multiply ionize at integer multiples of the potential energy of atomic hydrogen, 27.2 eV . The reaction involves a nonradiative energy transfer to form a hydrogen atom that is lower in energy than unreacted atomic hydrogen with the release of energy. One such atomic catalytic system involves Rb^+ from $RbNO_3$. Since the second ionization energy of rubidium is 27.28 eV , the reaction Rb^+ to Rb^{2+} has a net enthalpy of reaction of 27.28 eV . Intense extreme ultraviolet (EUV) emission was observed from incandescently heated atomic hydrogen and the atomized Rb^+ catalyst that generated an anomalous plasma at low temperatures (e.g. $\approx 10^3\text{ K}$) and an extraordinary low field strength of about $1\text{--}2\text{ V/cm}$. No emission was observed with $RbNO_3$ or hydrogen alone or when noncatalysts, $Mg(NO_3)_2$ or $Al(NO_3)_3$, replaced $RbNO_3$ with hydrogen. Emission was observed from Rb^{2+} that confirmed the resonant nonradiative energy transfer of 27.2 eV from atomic hydrogen to atomic Rb^+ . The catalysis product, a lower-energy hydrogen atom, was predicted to be a highly reactive intermediate which further reacts to form a novel hydride ion. The predicted hydride ion of hydrogen catalysis by Rb^+ is the hydride ion $H^-(1/2)$. This ion was observed spectroscopically at 407 nm corresponding to its predicted binding energy of 3.05 eV .

I. INTRODUCTION

Based on the solution of a Schrödinger-type wave equation with a nonradiative boundary condition based on Maxwell's equations, Mills [1-35] predicts that atomic hydrogen may undergo a catalytic reaction with certain atomized elements or certain gaseous ions which singly or multiply ionize at integer multiples of the potential energy of atomic hydrogen, 27.2 eV . For example, cesium atoms ionize at an integer multiple of the potential energy of atomic hydrogen, $m \cdot 27.2\text{ eV}$. The enthalpy of ionization of Cs to Cs^{2+} has a net enthalpy of reaction of 27.05135 eV , which is equivalent to $m=1$ [36]. And, the reaction Ar^+ to Ar^{2+} has a net enthalpy of reaction of 27.63 eV , which is equivalent to $m=1$ [36]. In each case, the reaction involves a nonradiative energy transfer to form a hydrogen atom that is lower in energy than unreacted atomic hydrogen. The product hydrogen atom has an energy state that corresponds to a fractional principal quantum number. Recent analysis of mobility and spectroscopy data of individual electrons in liquid helium show direct experimental confirmation that electrons may have fractional principal quantum energy levels [5].

Emission was observed previously from a continuum state of Cs^{2+} and Ar^{2+} at 53.3 nm and 45.6 nm , respectively [13]. The single emission feature with the absence of the other corresponding Rydberg series of lines from these species confirmed the resonant nonradiative energy transfer of 27.2 eV from atomic hydrogen to atomic cesium or Ar^+ . The catalysis product, a lower-energy hydrogen atom, was predicted to be a highly reactive intermediate which further reacts to form a novel hydride ion. The predicted hydride ion of hydrogen catalysis by either cesium atom or Ar^+ catalyst is the hydride ion $\text{H}^-(1/2)$. This ion was observed spectroscopically at 407 nm corresponding to its predicted binding energy of 3.05 eV .

The catalyst mechanism of potassium was also confirmed spectroscopically [12]. The first, second, and third ionization energies of potassium are 4.34066 eV , 31.63 eV , and 45.806 eV , respectively. The triple ionization ($t=3$) reaction of K to K^{3+} , then, has a net enthalpy of reaction of 81.7766 eV , which is equivalent to $3 \cdot 27.2\text{ eV}$. Characteristic emission was observed from K^{3+} which confirmed the resonant nonradiative energy

transfer of $3 \cdot 27.2 \text{ eV}$ from atomic hydrogen to atomic potassium. The predicted $H^-(1/4)$ hydride ion of hydrogen catalysis by potassium catalyst was observed at 110 nm corresponding to its predicted binding energy of 11.2 eV . The catalytic reactions with the formation of the hydride ions are given in the Appendix.

Additional prior related studies that support the possibility of a novel reaction of atomic hydrogen which produces a chemically generated or assisted plasma (rt-plasma) and produces novel hydride compounds include extreme ultraviolet (EUV) spectroscopy [6-9, 11-18, 21-23], characteristic emission from catalysis and the hydride ion products [9-13], lower-energy hydrogen emission [4, 6, 7-8, 17], plasma formation [9, 11-15, 21-22, 24-25], Balmer α line broadening [7, 9, 11, 14-15, 17-19], elevated electron temperature [7, 17], anomalous plasma afterglow duration [24-25], power generation [7, 9, 14-17, 19-21, 32], and analysis of chemical compounds [26-32].

Typically the emission of vacuum ultraviolet light from hydrogen gas is achieved using discharges at high voltage, synchrotron devices, high power inductively coupled plasma generators, or a plasma is created and heated to extreme temperatures by RF coupling (e.g. $>10^6 \text{ K}$) with confinement provided by a toroidal magnetic field. Observation of intense EUV emission at low temperatures (e.g. $\approx 10^3 \text{ K}$) from atomic hydrogen and certain atomized elements or certain gaseous ions [9, 11-15, 21-22, 24-25] has been reported previously. The only pure elements that were observed to emit EUV were those wherein the ionization of ι electrons from an atom to a continuum energy level is such that the sum of the ionization energies of the ι electrons is approximately $m \cdot 27.2 \text{ eV}$ where ι and m are each an integer. K , Cs , and Sr atoms and Rb^+ ion ionize at integer multiples of the potential energy of atomic hydrogen and caused emission. Whereas, the chemically similar atoms, Na , Mg , and Ba , do not ionize at integer multiples of the potential energy of atomic hydrogen and caused no emission.

The observed EUV emission could not be explained by conventional chemistry; rather, it must have been due to a novel chemical reaction between catalyst and atomic hydrogen. The catalysis of hydrogen involves the nonradiative transfer of energy from atomic hydrogen to a catalyst which may then release the transferred energy by radiative and

nonradiative mechanisms. As a consequence of the nonradiative energy transfer, the hydrogen atom becomes unstable and emits further energy until it achieves a lower-energy nonradiative state having a principal energy level given by Eqs. (1-2) of the Appendix.

The energy released during catalysis may undergo internal conversion and ionize or excite molecular and atomic hydrogen resulting in hydrogen emission which includes well characterized ultraviolet lines such as the Lyman series. A search for the predicted Lyman series emission due to the catalyst mechanism comprising the nonradiative transfer of 27.2 eV from atomic hydrogen to Rb^+ to form Rb^{2+} , and emission of the hydride ion product $H^-(1/2)$ was performed using EUV and visible (VIS) spectroscopy. (The catalytic reaction of Rb^+ and binding energy of the product hydride $H^-(1/2)$ are given in the Appendix.)

II. EXPERIMENTAL

A. EUV and Visible Spectroscopy

Due to the extremely short wavelength of this radiation, "transparent" optics do not exist for EUV spectroscopy. Therefore, a windowless arrangement was used wherein the source was connected to the same vacuum vessel as the grating and detectors of the EUV spectrometer. Differential pumping permitted a high pressure in the cell as compared to that in the spectrometer. This was achieved by pumping on the cell outlet and pumping on the grating side of the collimator that served as a pin-hole inlet to the optics. The spectrometer was continuously evacuated to 10^{-4} – 10^{-6} Torr by a turbomolecular pump with the pressure read by a cold cathode pressure gauge. The EUV spectrometer was connected to the cell light source with a 1.5 mm X 5 mm collimator which provided a light path to the slits of the EUV spectrometer. The collimator also served as a flow constrictor of gas from the cell. Valves were between the cell and the mechanical pump, the cell and the monochromator, and the monochromator and its turbo pump. The cell was operated under gas flow conditions while maintaining a constant gas pressure in the cell with a mass flow controller.

EUV and VIS spectra were recorded on light emitted from plasmas of hydrogen with $RbNO_3$. The experimental set up shown in Figure 1 comprised a quartz cell which was 500 mm in length and 50 mm in diameter. The entire quartz cell was enclosed in an Alumina insulation package. Several K-type thermocouples were located in the insulation. The thermocouples were monitored with a multichannel computer data acquisition system. A Pyrex cap sealed to the quartz cell with a Viton O ring and a C-clamp incorporated ports for gas inlet, outlet, and photon detection. A tungsten filament (0.508 mm in diameter and 800 cm in length, total resistance $\sim 2.5 \Omega$) heater and hydrogen dissociator were in the quartz tube as well as a cylindrical titanium screen (300 mm long and 40 mm in diameter) that served as a second hydrogen dissociator. The filament was coiled on a grooved ceramic tube support to maintain its shape when heated. The return lead passed through the inside of the ceramic tube. The filament leads were covered by a Alumina sheath.

The light emission phenomena was studied for 1.) H_2 alone, 2.) $Mg(NO_3)_2$ alone, 3.) $Al(NO_3)_3$ alone, 4.) $RbNO_3$ alone, 5.) $Mg(NO_3)_2$ with flowing hydrogen, 6.) $Al(NO_3)_3$ with flowing hydrogen, and 7.) $RbNO_3$ with flowing hydrogen. The inorganic test materials were coated on the titanium screen dissociator by the method of wet impregnation. The screen was coated by dipping it in a 0.6 M $RbNO_3/10\% H_2O_2$, 0.6 M $Mg(NO_3)_2/10\% H_2O_2$, or 0.6 M $Al(NO_3)_3/10\% H_2O_2$ aqueous solution, and the crystalline material was dried on the surface by heating for 12 hours in a drying oven at 130 °C. A new dissociator was used for each experiment. The test materials were volatilized by the filament heater.

The titanium screen was electrically floated. Power was applied to the filament by a DC power supply which was controlled by a constant power controller. The cell was operated with 300 W or less input power which corresponded to a cell wall temperature of about 700 °C. The temperature of the tungsten filament was estimated to be in the range 1100 to 1500 °C.

The cell was operated under gas flow conditions while maintaining a constant gas pressure in the cell. The hydrogen was ultrahigh purity. The gas pressure inside the cell was maintained at about 300 mTorr with a hydrogen flow rate of 5.5 sccm controlled by a 0-20 sccm range mass flow controller (MKS 1179A21CS1BB) with a readout (MKS type 246).

The cell pressure was monitored by a 0-10 Torr MKS Baratron absolute pressure gauge.

The light emission was introduced to an EUV spectrometer for spectral measurement. The spectrometer was a McPherson 0.2 meter monochromator (Model 302, Seya-Namioka type) equipped with a 1200 lines/mm holographic grating with a platinum coating. The wavelength region covered by the monochromator was 30–560 nm. A channel electron multiplier (CEM) was used to detect the EUV light. The wavelength resolution was about 1 nm (FWHM) with an entrance and exit slit width of 300 μ m. The vacuum inside the monochromator was maintained below 5×10^{-4} Torr by a turbo pump. The Lyman α emission was recorded as a function of time after the filament was turned on. The EUV spectra (50–90 nm) and (40–160 nm) of the $RbNO_3/H_2$ cell emission were recorded at about the point of the maximum Lyman α emission.

The EUV/UV/VIS spectrum (40–560 nm) of the cell emission with hydrogen alone was recorded with a photomultiplier tube (PMT) and a sodium salicylate scintillator. The PMT (Model R1527P, Hamamatsu) used has a spectral response in the range of 185–680 nm with a peak efficiency at about 400 nm. The scan interval was 0.4 nm. The inlet and outlet slit were 500 μ m with a corresponding wavelength resolution of 1.5 nm.

The VIS spectrum (380–500 nm) of the cell emission was according to the method of the EUV/UV/VIS spectrum (40–560 nm) except that the inlet and outlet slit were 300 μ m with a corresponding wavelength resolution of 1 nm. The spectrum was recorded two hours after a plasma formed.

B. Standard Rubidium and Hydrogen Emission Spectra

The standard EUV emission spectrum of rubidium was obtained with a gas discharge cell comprising a five-way stainless steel cross that served as the anode with a hollow stainless steel cathode that was coated with $RbNO_3$ by the same procedure used to coat the titanium dissociator. The five-way cross was pressurized with 1 Torr of hydrogen to initiate the discharge. The hydrogen was then evacuated so that only rubidium lines were observed. The DC voltage at the time the EUV spectrum was

recorded was 300 V. The standard EUV emission spectrum of hydrogen was obtained in the same manner as the standard rubidium spectrum, except that the cathode was not coated.

III. RESULTS

A. EUV Spectroscopy

The intensity of the Lyman α emission as a function of time was recorded for four hours from the gas cell at a cell temperature of 700 °C comprising a tungsten filament, a titanium dissociator, and each of the controls $Mg(NO_3)_2$ alone and $Al(NO_3)_3$ alone, as well as the catalyst $RbNO_3$ alone. No Lyman α emission was observed. Similarly, a plasma did not form, and no EUV emission was observed with hydrogen alone at 300 mtorr with a flow rate of 5.5 sccm or with the control materials and the flowing hydrogen. The typical UV/VIS spectrum (40–560 nm) of a control is shown in Figure 2. No emission was observed except for the blackbody filament radiation at the longer wavelengths.

The intensity of the Lyman α emission as a function of time with vaporized Rb^+ from $RbNO_3$ with flowing hydrogen was recorded. Strong EUV emission was observed from vaporized catalyst only when hydrogen was present. The EUV spectrum (40–160 nm) of the cell emission recorded at about the point of the maximum Lyman α emission is shown in Figure 3.

B. EUV Emission of Rb^+ Catalyst

The EUV spectrum (50–90 nm) of the emission of the $RbNO_3/H_2$ gas cell (top curve) and the standard rubidium discharge plasma according to Sec. IIB (bottom curve) are shown in Figure 4. Line emission corresponding to Rb^{2+} was observed at 81.59 nm, 59.1 nm, 58.1 nm, 55.6 nm, and 53.3 nm. Rb^+ was observed at 74.15 nm, 71.1 nm, 69.7 nm, and 64.38 nm. The assignments of the Rb^{2+} and Rb^+ lines were confirmed by the NIST tables [37].

C. 407 nm Emission with Rb^+ Catalyst

The VIS spectra (380–500 nm) of the cell emission of the $RbNO_3/H_2$ gas cell (top curve) and of standard hydrogen (bottom curve) are shown in Figure 5. From the comparison, a novel broad peak was observed at 407 nm which was not due to rubidium emission. The known Rb I peaks are indicated in Figure 5. Molecular hydrogen has emission at 407 nm, but the assignment to molecular hydrogen was eliminated since the other peaks of hydrogen were not observed at comparable intensity. The novel broad 407 nm peak was observed only with Rb^+ and atomic hydrogen present over an extended reaction time. These results are consistent with the formation of $H^-(1/2)$ from the catalysis of atomic hydrogen by Rb^+ .

IV. DISCUSSION

A plasma that emitted intense EUV formed at low temperatures (e.g. $\approx 10^3$ K) from atomic hydrogen and Rb^+ catalyst which was vaporized by heating. No possible chemical reactions of the tungsten filament, the dissociator, the vaporized test material, and 300 mTorr hydrogen at a cell temperature of 700 °C could be found which accounted for the hydrogen Lyman α line emission. In fact, no known possible chemical reaction releases enough energy to form a hydrogen plasma and excite Lyman α emission from hydrogen. The emission was not observed with catalyst or hydrogen alone. Intense emission was observed for catalyst with hydrogen gas, but no emission was observed when magnesium or aluminum nitrate replaced rubidium nitrate catalyst with hydrogen. This result indicates that the emission was due to a reaction of the catalyst with hydrogen.

Rubidium ions ionize at an integer multiple of the potential energy of atomic hydrogen, 27.2 eV, $m \cdot 27.2$ eV wherein m is an integer. The reaction Rb^+ to Rb^{2+} has a net enthalpy of reaction of 27.28 eV, which is equivalent to $m=1$. Characteristic emission was observed from Rb^{2+} which confirmed the resonant nonradiative energy transfer of 27.2 eV from atomic hydrogen to Rb^+ (Eq. (5)). With a highly conductive plasma, the voltage of the cell was about 20 V, and the field strength was about

1-2 V/cm which was too low to ionize Rb^+ to Rb^{2+} . The Rb^{2+} lines generated in the incandescently heated cell and due to the catalyst reaction of atomic hydrogen were confirmed by a high voltage discharge and NIST tables [37].

Similar low-voltage hydrogen catalysis plasmas formed with hydrogen-potassium mixtures have been reported previously [24-25] wherein the plasma decayed with a two second half-life when the electric field was actually set to zero. This was the thermal decay time of the filament which dissociated molecular hydrogen to atomic hydrogen. This experiment showed that hydrogen line emission was occurring even though the voltage between the heater wires was set to and measured to be zero and indicated that the emission was due to a reaction of potassium atoms with atomic hydrogen. Potassium atoms ionize at an integer multiple of the potential energy of atomic hydrogen, $m \cdot 27.2 \text{ eV}$. The enthalpy of ionization of K to K^{3+} has a net enthalpy of reaction of 81.7426 eV , which is equivalent to $m=3$.

An excessive plasma afterglow duration was also previously reported for $RbNO_3$ and other catalysts [25]. A catalytic plasma of hydrogen and certain alkali ions formed at low temperatures ($<10^3 \text{ K}$) as recorded via EUV spectroscopy and the hydrogen Balmer and alkali line emissions in the visible range. The observed plasma formed from atomic hydrogen generated at a tungsten filament that heated a titanium dissociator and one of potassium, rubidium, cesium, and their carbonates and nitrates. These atoms and ions ionize to provide a net enthalpy of reaction of an integer multiple of the potential energy of atomic hydrogen ($m \cdot 27.2 \text{ eV}$, $m = \text{integer}$) to within 0.17 eV and comprise only a single ionization in the case of a potassium or rubidium ion. Whereas, the chemically similar atoms of sodium and sodium and lithium carbonates and nitrates which do not ionize with these constraints caused no emission. To test the electric dependence of the emission, the weak electric field of about 1 V/cm was set and measured to be zero in $<0.5 \times 10^{-6} \text{ sec}$. An afterglow duration of about one to two seconds was recorded in the case of potassium, rubidium, cesium, K_2CO_3 , $RbNO_3$, and $CsNO_3$. Hydrogen line or alkali line emission was occurring even though the voltage between the heater wires was set to and measured to be zero. These atoms and ions ionize to provide a net enthalpy of reaction of an

integer multiple of the potential energy of atomic hydrogen to within less than the thermal energies at $\approx 10^3 K$ and comprise only a single ionization in the case of a potassium or rubidium ion. Since the thermal decay time of the filament for dissociation of molecular hydrogen to atomic hydrogen was similar to the plasma afterglow duration, the emission was determined to be due to a reaction of atomic hydrogen with each of the atoms or ions that did not require the presence of an electric field to be functional.

Rb^+ is predicted to catalyze hydrogen to form $H\left[\frac{a_H}{2}\right]$ which reacts with an electron to form $H^-(1/2)$. The predicted $H^-(1/2)$ hydride ion of hydrogen catalysis by Rb^+ was observed spectroscopically at 407 nm corresponding to its predicted binding energy of 3.05 eV. The hydride reaction product formed over time.

In a recently submitted paper [11], $H^-(1/2)$, the hydride ion catalyst product of K^+/K^+ or Rb^+ , was reported to have been observed by high resolution visible spectroscopy as a broad peak at 407.00 nm with a FWHM of 0.14 nm corresponding to its predicted binding energy of 3.0468 eV. From the electron g factor, bound-free hyperfine structure lines of $H^-(1/2)$ were predicted with energies E_{HF} given by $E_{HF} = j^2 3.0056 \times 10^{-5} + 3.0575 \text{ eV}$ (j is an integer) as an inverse Rydberg-type series that converges at increasing wavelengths and terminates at 3.0575 eV—the hydride spin-pairing energy plus the binding energy. The high resolution visible plasma emission spectra in the region of 400.0 nm to 406.0 nm matched the predicted emission lines for $j=1$ to $j=37$ to within a 1 part per 10^5 .

The formation of compounds having novel hydride ions $H^-(1/p)$ would be substantial evidence supporting catalysis of hydrogen as the mechanism of observed rt-plasmas and further support the spectroscopic identification of $H^-(1/p)$ (p is an integer). Compounds containing novel hydride ions have been isolated as products of the reaction of atomic hydrogen with atoms and ions identified as catalysts in previously reported EUV studies [26-32]. The novel hydride compounds were identified analytically by techniques such as time of flight secondary ion mass spectroscopy, X-ray photoelectron spectroscopy, and 1H nuclear magnetic resonance spectroscopy. For example, the time of flight

secondary ion mass spectroscopy showed a large hydride peak in the negative spectrum. The X-ray photoelectron spectrum showed large metal core level shifts due to binding with the hydride as well as novel hydride peaks. The 1H nuclear magnetic resonance spectrum showed significantly upfield shifted peaks which corresponded to and identified novel hydride ions.

V. CONCLUSION

Characteristic emission was observed from Rb^{2+} which confirmed the resonant nonradiative energy transfer of 27.2 eV from atomic hydrogen to Rb^+ (Eq. (5)). The predicted $H^-(1/2)$ hydride ion of hydrogen catalysis by Rb^+ catalyst given by Eqs. (5-7) and Eq. (18) was observed spectroscopically at 407 nm corresponding to its predicted binding energy of 3.05 eV .

APPENDIX

A. Catalysts

The mechanism of EUV emission and formation of a novel hydride ion can not be explained by the conventional chemistry of hydrogen; rather, it must have been due to a novel chemical reaction between catalyst and atomic hydrogen. Mills [1-35] predicts that certain atoms or ions serve as catalysts to release energy from hydrogen to produce an increased binding energy hydrogen atom called a *hydrino atom* having a binding energy of

$$\text{Binding Energy} = \frac{13.6 \text{ eV}}{n^2} \quad (1)$$

where

$$n = \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \dots, \frac{1}{p} \quad (2)$$

and p is an integer greater than 1, designated as $H\left[\frac{a_H}{p}\right]$ where a_H is the radius of the hydrogen atom. Hydrinos are predicted to form by reacting an ordinary hydrogen atom with a catalyst having a net enthalpy of reaction of about

$$m \cdot 27.2 \text{ eV} \quad (3)$$

where m is an integer. This catalysis releases energy from the hydrogen atom with a commensurate decrease in size of the hydrogen atom, $r_n = na_H$. For example, the catalysis of $H(n=1)$ to $H(n=1/2)$ releases 40.8 eV, and the hydrogen radius decreases from a_H to $\frac{1}{2}a_H$.

The excited energy states of atomic hydrogen are also given by Eq. (1) except that

$$n = 1, 2, 3, \dots \quad (4)$$

The $n=1$ state is the "ground" state for "pure" photon transitions (the $n=1$ state can absorb a photon and go to an excited electronic state, but it cannot release a photon and go to a lower-energy electronic state). However, an electron transition from the ground state to a lower-energy state is possible by a nonradiative energy transfer such as multipole coupling or a resonant collision mechanism. These lower-energy states

have fractional quantum numbers, $n = \frac{1}{\text{integer}}$. Processes that occur

without photons and that require collisions are common. For example, the exothermic chemical reaction of $H+H$ to form H_2 does not occur with the emission of a photon. Rather, the reaction requires a collision with a third body, M , to remove the bond energy- $H+H+M \rightarrow H_2+M^*$ [38]. The third body distributes the energy from the exothermic reaction, and the end result is the H_2 molecule and an increase in the temperature of the system. Some commercial phosphors are based on nonradiative energy transfer involving multipole coupling. For example, the strong absorption strength of Sb^{3+} ions along with the efficient nonradiative transfer of excitation from Sb^{3+} to Mn^{2+} , are responsible for the strong manganese luminescence from phosphors containing these ions [39].

Similarly, the $n=1$ state of hydrogen and the $n = \frac{1}{\text{integer}}$ states of hydrogen are nonradiative, but a transition between two nonradiative states, say $n=1$ to $n=1/2$, is possible via a nonradiative energy transfer. In these cases, during the transition the electron couples to another electron transition, electron transfer reaction, or inelastic scattering reaction which can absorb the exact amount of energy that must be removed from the hydrogen atom to cause the transition. Thus, a catalyst provides a net positive enthalpy of reaction of $m \cdot 27.2 \text{ eV}$ (i.e. it absorbs $m \cdot 27.2 \text{ eV}$ where m is an integer). Certain atoms or ions serve as catalysts by accepting energy from hydrogen atoms through a nonradiative resonant transfer. The catalyst may then release the transferred energy by radiative and nonradiative mechanisms. As a consequence of the nonradiative energy transfer, the hydrogen atom becomes unstable and emits further energy until it achieves a lower-energy nonradiative state having a principal energy level given by Eqs. (1-2).

Rubidium Ion

Rubidium ions can provide a net enthalpy of a multiple of that of the potential energy of the hydrogen atom. The second ionization energy of rubidium is 27.28 eV . The reaction Rb^+ to Rb^{2+} has a net enthalpy of reaction of 27.28 eV , which is equivalent to $m=1$ in Eq. (3).

$$27.28 \text{ eV} + \text{Rb}^+ + \text{H}\left[\frac{a_H}{p}\right] \rightarrow \text{Rb}^{2+} + e^- + \text{H}\left[\frac{a_H}{(p+1)}\right] + [(p+1)^2 - p^2] \times 13.6 \text{ eV} \quad (5)$$

$$\text{Rb}^{2+} + e^- \rightarrow \text{Rb}^+ + 27.28 \text{ eV} \quad (6)$$

The overall reaction is

$$\text{H}\left[\frac{a_H}{p}\right] \rightarrow \text{H}\left[\frac{a_H}{(p+1)}\right] + [(p+1)^2 - p^2] \times 13.6 \text{ eV} \quad (7)$$

Alkali metal nitrates are extraordinarily volatile and can be distilled at 350-500 °C [40]. RbNO_3 is the favored candidate for providing gaseous Rb^+ ions. Rb^+ ion emission was observed in the EUV and VIS spectrum.

Cesium

A catalytic system is provided by the ionization of two electrons from a cesium atom each to a continuum energy level such that the sum of the ionization energies of the two electrons is approximately 27.2 eV. The first and second ionization energies of cesium are 3.89390 eV and 23.15745 eV, respectively [36]. The double ionization ($t=2$) reaction of Cs to Cs^{2+} , then, has a net enthalpy of reaction of 27.05135 eV, which is equivalent to $m=1$ in Eq. (3).

$$27.05135 \text{ eV} + \text{Cs}(m) + \text{H}\left[\frac{a_H}{p}\right] \rightarrow \text{Cs}^{2+} + 2e^- + \text{H}\left[\frac{a_H}{(p+1)}\right] + [(p+1)^2 - p^2] \times 13.6 \text{ eV} \quad (8)$$

$$\text{Cs}^{2+} + 2e^- \rightarrow \text{Cs}(m) + 27.05135 \text{ eV} \quad (9)$$

And, the overall reaction is

$$\text{H}\left[\frac{a_H}{p}\right] \rightarrow \text{H}\left[\frac{a_H}{(p+1)}\right] + [(p+1)^2 - p^2] \times 13.6 \text{ eV} \quad (10)$$

Argon Ion

Argon ions can provide a net enthalpy of a multiple of that of the potential energy of the hydrogen atom. The second ionization energy of argon is 27.63 eV. The reaction Ar^+ to Ar^{2+} has a net enthalpy of reaction of 27.63 eV, which is equivalent to $m=1$ in Eq. (3).

$$27.63 \text{ eV} + \text{Ar}^+ + H\left[\frac{a_H}{p}\right] \rightarrow \text{Ar}^{2+} + e^- + H\left[\frac{a_H}{(p+1)}\right] + [(p+1)^2 - p^2]X13.6 \text{ eV} \quad (11)$$

$$\text{Ar}^{2+} + e^- \rightarrow \text{Ar}^+ + 27.63 \text{ eV} \quad (12)$$

And, the overall reaction is

$$H\left[\frac{a_H}{p}\right] \rightarrow H\left[\frac{a_H}{(p+1)}\right] + [(p+1)^2 - p^2]X13.6 \text{ eV} \quad (13)$$

Potassium

An additional catalytic system involves potassium atoms. The first, second, and third ionization energies of potassium are 4.34066 eV, 31.63 eV, 45.806 eV, respectively [36]. The triple ionization ($t=3$) reaction of K to K^{3+} , then, has a net enthalpy of reaction of 81.7766 eV, which is equivalent to $m=3$ in Eq. (3).

$$81.7766 \text{ eV} + K(m) + H\left[\frac{a_H}{p}\right] \rightarrow K^{3+} + 3e^- + H\left[\frac{a_H}{(p+3)}\right] + [(p+3)^2 - p^2]X13.6 \text{ eV} \quad (14)$$

$$K^{3+} + 3e^- \rightarrow K(m) + 81.7766 \text{ eV} \quad (15)$$

And, the overall reaction is

$$H\left[\frac{a_H}{p}\right] \rightarrow H\left[\frac{a_H}{(p+3)}\right] + [(p+3)^2 - p^2]X13.6 \text{ eV} \quad (16)$$

B. Hydride Ion

A novel hydride ion having extraordinary chemical properties given by Mills [1] is predicted to form by the reaction of an electron with a hydrino (Eq. (17)). The resulting hydride ion is referred to as a hydrino hydride ion, designated as $H^-(1/p)$.

$$H\left[\frac{a_H}{p}\right] + e^- \rightarrow H^-(1/p) \quad (17)$$

The hydrino hydride ion is distinguished from an ordinary hydride ion having a binding energy of 0.8 eV. The hydrino hydride ion is

predicted [1] to comprise a hydrogen nucleus and two indistinguishable electrons at a binding energy according to the following formula:

$$\text{Binding Energy} = \frac{\hbar^2 \sqrt{s(s+1)}}{8\mu_e a_0^2 \left[\frac{1 + \sqrt{s(s+1)}}{p} \right]^2} - \frac{\pi\mu_0 e^2 \hbar^2}{m_e^2 a_0^3} \left(1 + \frac{2^2}{\left[\frac{1 + \sqrt{s(s+1)}}{p} \right]^3} \right) \quad (18)$$

where p is an integer greater than one, $s=1/2$, \hbar is Planck's constant bar, μ_0 is the permeability of vacuum, m_e is the mass of the electron, μ_e is the reduced electron mass, a_0 is the Bohr radius, and e is the elementary charge. The ionic radius is

$$r_1 = \frac{a_0}{p} (1 + \sqrt{s(s+1)}); s = \frac{1}{2} \quad (19)$$

From Eq. (19), the radius of the hydrino hydride ion $H^-(1/p)$; $p = \text{integer}$ is $\frac{1}{p}$ that of ordinary hydride ion, $H^-(1/1)$.

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Figure Captions

Figure 1. The experimental set up comprising a gas cell light source and an EUV spectrometer which was differentially pumped.

Figure 2. The EUV/UV/VIS spectrum (40–560 nm) of the cell emission from the gas cell at a cell temperature of 700 °C comprising a tungsten filament, a titanium dissociator, and 300 mTorr hydrogen that was recorded with a photomultiplier tube (PMT) and a sodium salicylate scintillator with an entrance and exit slit width of 500 μm . No emission was observed except for the blackbody filament radiation at the longer wavelengths.

Figure 3. The EUV spectrum (40–160 nm) of the cell emission recorded at about the point of the maximum Lyman α emission from the gas cell at a cell temperature of 700 °C comprising a tungsten filament, a titanium dissociator, 300 mTorr hydrogen, and vaporized Rb^+ from RbNO_3 that was recorded with a CEM. Strong Lyman series emission was observed.

Figure 4. The EUV spectrum (50–90 nm) of the emission of the RbNO_3/H_2 gas cell (top curve) and the standard discharge rubidium plasma (bottom curve). Line emission corresponding to Rb^{2+} was observed at 81.59 nm, 59.1 nm, 58.1 nm, 55.6 nm, and 53.3 nm. Rb^+ was observed at 74.15 nm, 71.1 nm, 69.7 nm, and 64.38 nm.

Figure 5. The VIS spectra (380–500 nm) of the cell emission of the RbNO_3/H_2 gas cell (top curve) and of standard hydrogen (bottom curve). A novel broad peak was observed at 407 nm which was not due to rubidium or hydrogen emission. The peak was assigned to $\text{H}^-(1/2)$ emission.

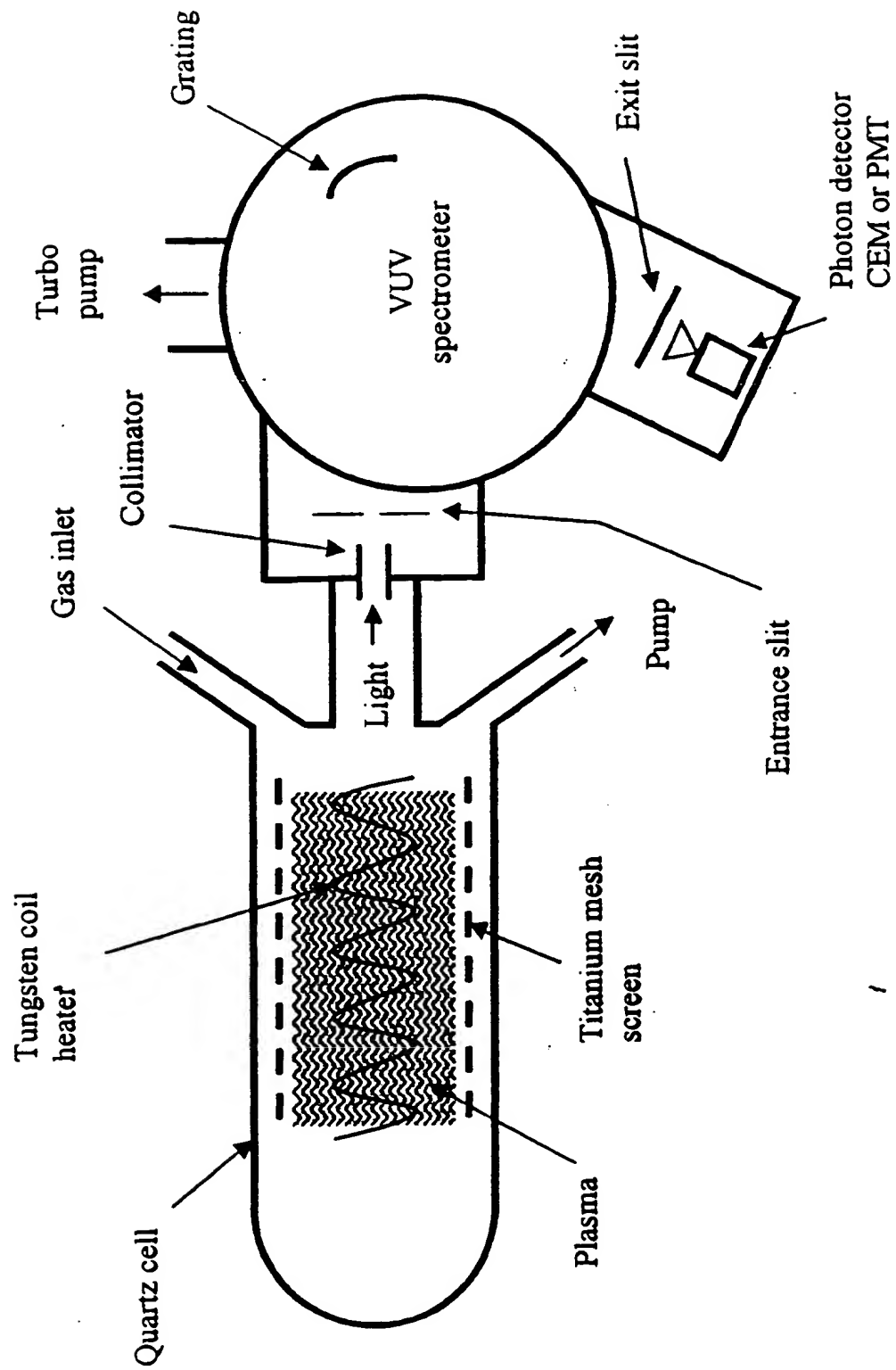


Fig. 1

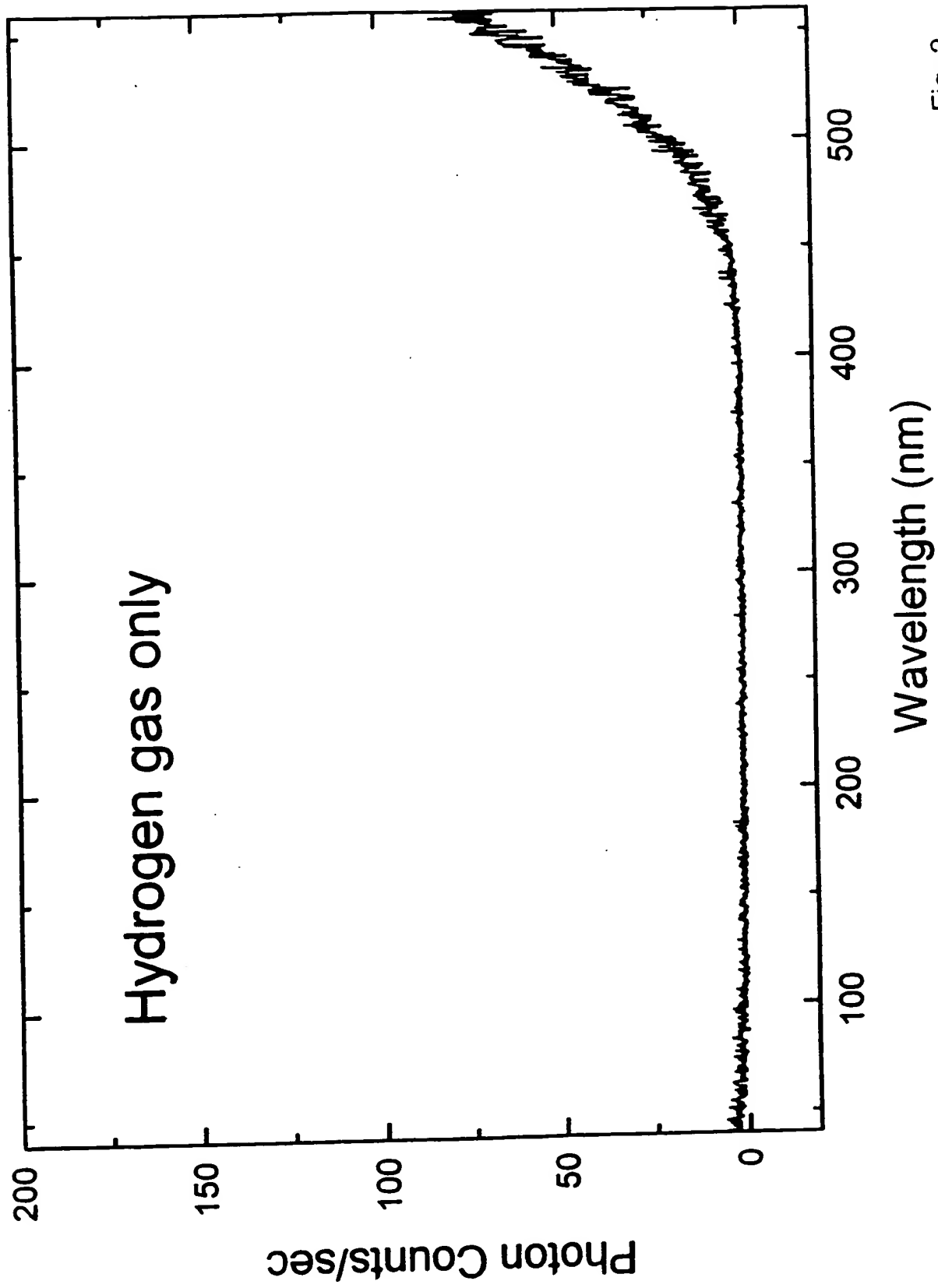


Fig. 2

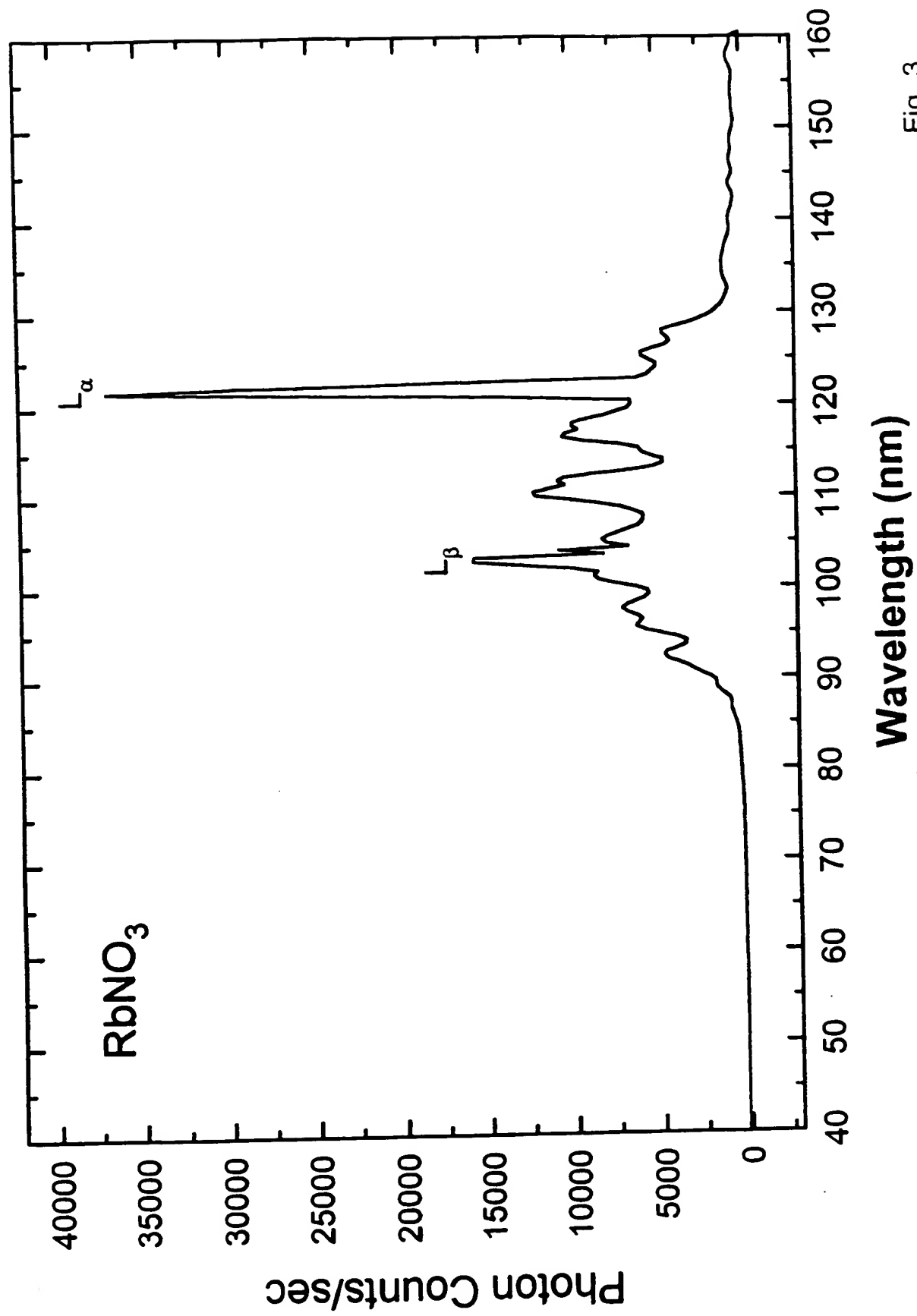


Fig. 3

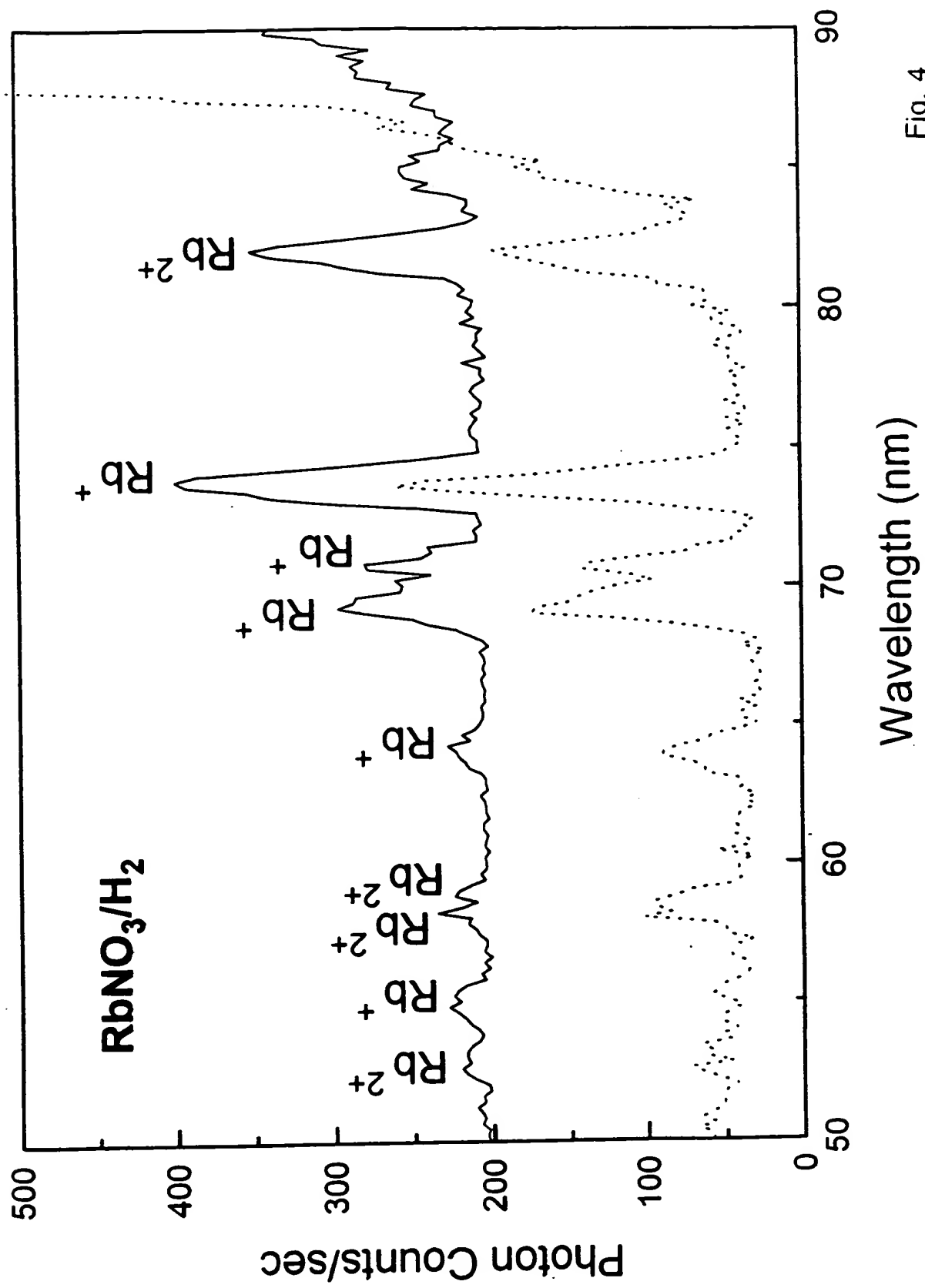


Fig. 4

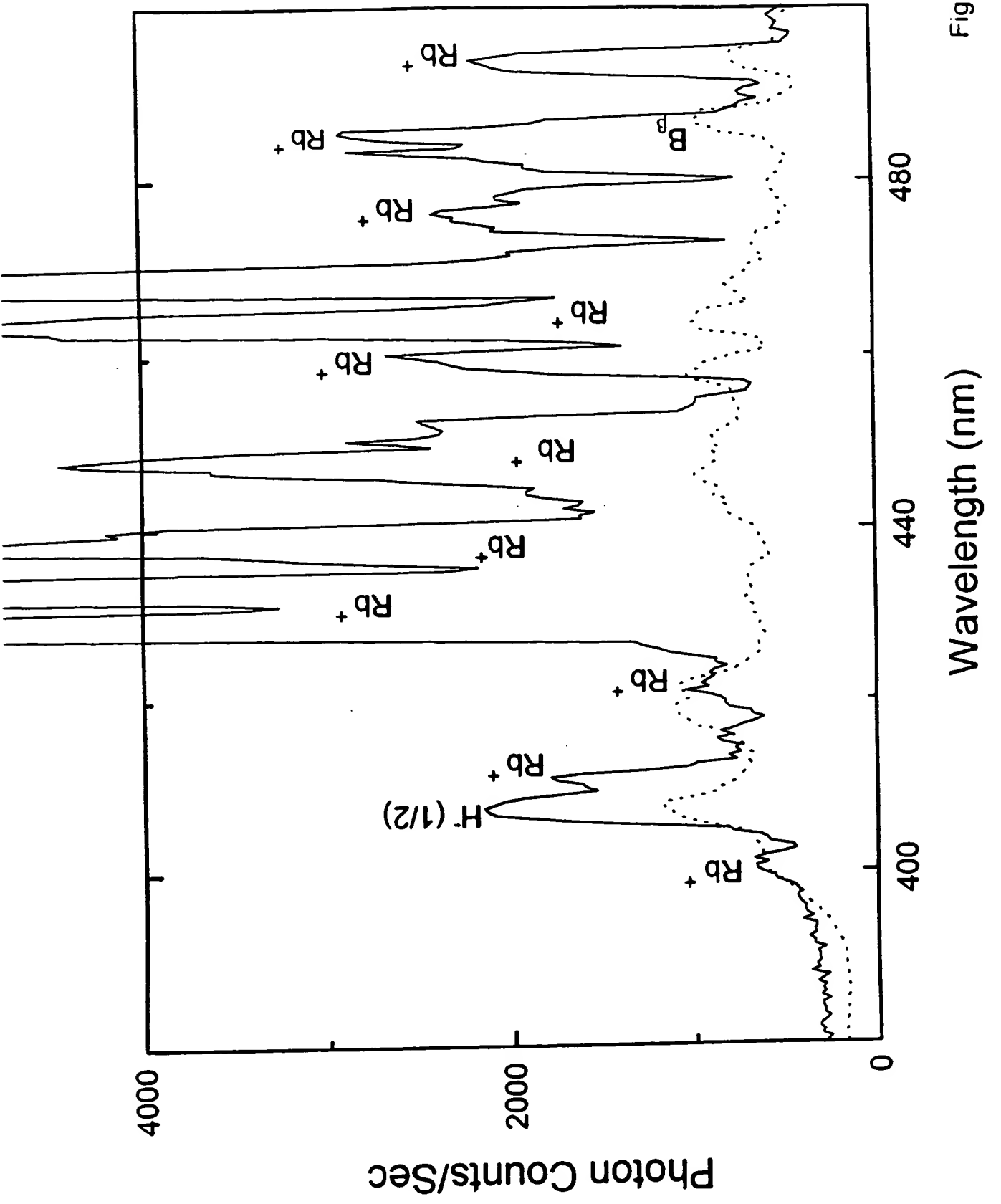


Fig. 5